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The HEC Hydrologic Modeling System

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THE HEC HYDROLOGIC MODELING SYSTEM

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ABSTRACT: The Hydrologic Modeling System is the Hydrologic Engineering Center's "next generation" software for precipitation-runoff simulation. The software will provide a variety of options for specifying observed or hypothetical meteorological inputs and for simulating losses, runoff transformation, and routing. Capabilities include a quasi-distributed runoff transformation that can be applied with gridded (e.g., radar) rainfall data. Soil-moisture accounting options that support period-of-record simulation will be provided, as will capability to simulate snow accumulation and melt. The software employs a graphical user interface and is designed for use in both X-Window and Microsoft Windows environments.
KEY TERMS: surface water hydrology; simulation; modeling.

INTRODUCTION

The Hydrologic Engineering Center (HEC) is developing a new generation of software for use in hydrologic engineering, water resource planning and project operation (Davis, 1993). The software for precipitation-runoff modeling is the Hydrologic Modeling System (HEC-HMS), a successor to the existing HEC-1, Flood Hydrograph Package (HEC, 1990). Release of the initial version of HEC-HMS is scheduled for 1996.

TECHNICAL FEATURES

The basic framework for simulation of basin runoff with HEC-HMS is similar to that in HEC-1. Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. An exception is that all subbasins having gridded rainfall are processed through the entire period of simulation prior to computations for remaining elements.

Computations are performed with SI (Système International d`Unites) units. However the user can choose to enter input and view output with units in the U.S Customary system.

The execution of a simulation with HEC-HMS requires specification of three sets of data. The first, labeled Basin Model, contains parameter and connectivity data for hydrologic elements. Types of element are: subbasin, routing reach, junction, reservoir, source, sink and diversion. The second set, labeled Precipitation Model, consists of meteorological data and information required to process it. The data

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may represent historical or hypothetical conditions. The third set, labeled Control Specifications, specifies a simulation time window, time interval, and initial values for state variables. A Project can consist of a number of data sets of each type. Figure 1 illustrates an opening screen in the HEC-HMS graphical user interface which lists Project components. A "run" is configured with one (each) Basin Model, Precipitation Model and Control Specification.

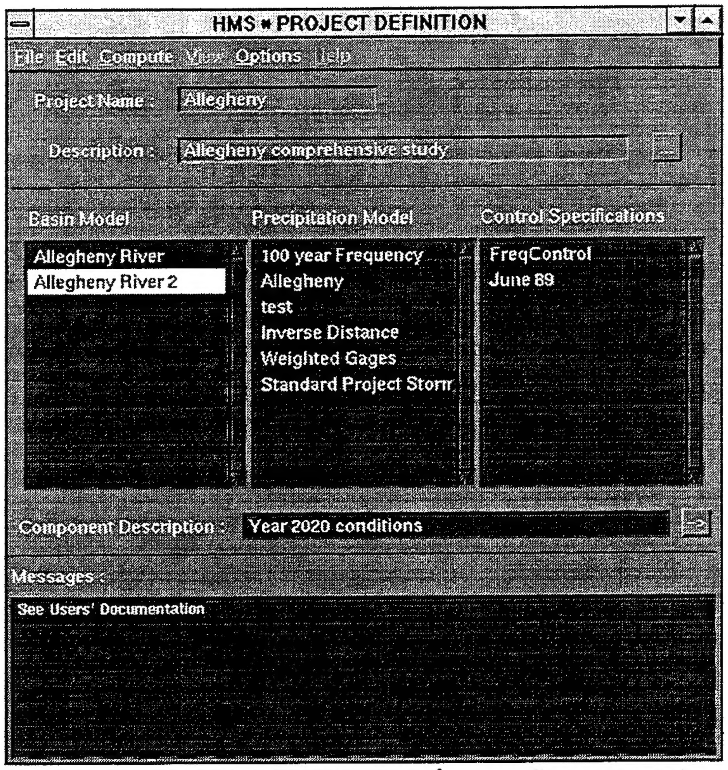

Figure 1. HEC-HMS Project Components

Basin Model

Subbasin runoff can be computed in either a lumped or quasi-distributed mode. In a lumped mode, precipitation and "losses" are spatially-averaged over a subbasin. In the quasi-distributed mode, rainfall is specified on a gridded basis, and loss and excess are tracked separately for each grid cell in a subbasin.

Losses

Options for calculating losses for event simulation include initial/constant, SCS Curve No., and Green and Ampt. For continuous simulation, a simple deficit/constant loss function can be used. The user specifies a soil moisture storage capacity which must be filled before excess can occur. The capacity is filled by rainfall, and depleted during rain-free periods at a depletion rate specified on a daily or monthly basis. When the capacity is filled, loss occurs at the specified constant rate. It is planned to incorporate detailed soil moisture accounting options in future versions of HEC-HMS.

Runoff Transformation

Transformation of precipitation excess to direct runoff can be achieved with unit hydrograph or kinematic wave methods. A unit hydrograph may be specified in tabular form, or in terms of parameters defined by Clark, Snyder or SCS methods. The kinematic wave method permits definition of two rectangular overland flow planes. Runoff from an overland flow plane may be routed through one or two collector/main channel(s) with kinematic wave or Muskingum Cunge methods.

ModClark Method

A quasi-distributed treatment of subbasin runoff can be achieved with the modClark method, which is based on the Clark conceptual runoff model (Clark, 1945). The Clark conceptual model employs two components (1) a translation hydrograph to reflect the travel (lag) time required for 1 unit of rainfall excess (occurring instantaneously) to reach the basin outlet from isochrone-delineated basin segments, and (2) a linear reservoir to represent natural storage effects. The translation hydrograph is routed through the linear reservoir; the resulting outflow is an instantaneous unit hydrograph. The two parameters of the Clark method are the time-of-concentration T_c (time base of the translation hydrograph), and the storage coefficient of the linear reservoir, R. Both parameters have units of time.

In the modClark method, grid cells are superposed on the basin (Figure 2), and rainfall and losses are tracked uniquely for each cell. Rainfall excess from each cell is lagged to the basin outlet and routed through a linear reservoir. The outflows from the linear reservoir are summed and baseflow is added to obtain a total-runoff hydrograph. Information required for each grid cell are its area within the subbasin and an index of travel time from the cell to the subbasin outlet. The travel time for a cell is obtained by multiplying the time of concentration for the subbasin by the ratio of the cell's time index to the time index for the most remote cell (i.e., the cell with the largest time index). A simple time index for a cell is the reciprocal of the travel length of the flow path to the subbasin outlet. Implicit in this measure is the assumption that the velocity of travel is constant in the subbasin.

An alternative time index is based on cell slope and area. The travel time through a cell is assumed to be related to the cell slope and to the accumulated area of all cells contributing runoff to the cell. That is, $v_{cell} \propto S^a * A^b$, where S is the cell slope, and A is the accumulated area of contributing cells. The accumulated area can be regarded as a surrogate for depth. A value of 0.5 has been found to be reasonable for both the a and b exponents (Maidment et al., 1995). The time index for a given cell is defined as the integral of ℓ_{cell}/v_{cell} along the flow path to the subbasin outlet, where ℓ_{cell} is the length of flow path through a cell.

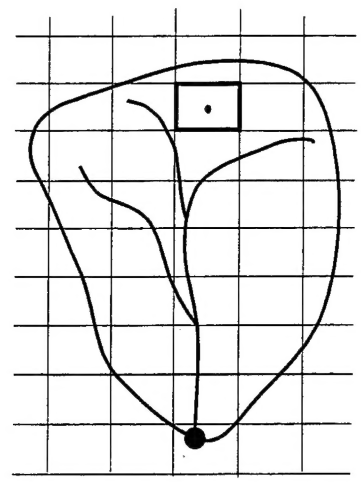

Figure 2. Basin with Rainfall Grid Superposed

A procedure has been developed (HEC, 1995a) to use a geographic information system (GIS) to produce cell data (area and time indices as defined above) for use with the modClark method. The procedure is based on processing digital elevation model (DEM) data such as is available for the continental U.S. from the USGS EROS Data Center (USGS, 1990). Once application of the GIS procedure has been completed, the resulting cell-parameter file is used by HEC-HMS with the modClark method. Thus GIS is used to preprocess data and is not required for subsequent application of the modClark method.

Routing

Routing options include Muskingum, Modified Puls and Muskingum Cunge methods. The latter may be invoked with standard geometric shapes (e.g., circle, trapezoid) or with cross sections defined with eight sets of X-Y coordinates and three Manning n values. Capability is also provided for routing through an uncontrolled reservoir, for which a relation between outflow and storage is required. If more sophisticated routing methods are required because of complex boundary conditions, hydrographs may be exported by HEC-HMS for use with software such as UNET (HEC, 1995b) which provides a numerical solution to the one-dimensional St. Venant equations.

Diversion

A diversion can be specified in terms of a tabular relation between inflow and diverted flow. The diverted hydrograph can be retrieved at a downstream location in a system network.

Precipitation Model

The precipitation model is the set of information required to define historical or hypothetical precipitation to be used in conjunction with a basin model. Types of hypothetical storm include frequency-

based and the Corps of Engineers' Standard Project Storm (Corps of Engineers, 1965). The latter is applicable only for drainage areas up to 2600 km^2 east of the Rocky Mountains. Frequency-based storms require that the user provide rainfall depths for various durations, sources of which include Technical Paper 40 (National Weather Service, 1961) and NOAA Atlas 2 (National Oceanic and Atmospheric Administration, 1973).

Several options are available for specifying historical precipitation: (1) utilize cell-based precipitation as required for the modClark method; (2) obtain spatial average precipitation from cell-based precipitation; (3) import previously determined spatially averaged precipitation; (4) specify gages and associated weights (e.g., from Theissen polygons);, or (5) specify gages and their locations, and weights and locations of index nodes, to be used in an automated inverse distance squared weighting. The latter method is useful in cases of missing data, as data from the next nearest gage is automatically used.

GRAPHICAL USER INTERFACE

The Graphical User Interface (GUI) provides a means for specification of information to be retrieved or stored (e.g., importation of data from a previously developed HEC-1 data file), specification of application-specific information (data and execution instructions), and viewing of results.

A significant component of the GUI is capability for schematic representation of a network of hydrologic elements (see Figure 3). The schematic can be used in the initial configuration of a basin model by generating, dragging into place and connecting (graphically) icons that represent components of a basin network. Once a schematic is developed, popup menus can be invoked by double-clicking an element (e.g., subbasin) icon to bring up an editor for that element. Data associated with the hydrologic element can be entered or edited in the editor. Another option in the popup menu enables display of results of a simulation for that element. Figure 4 shows graphical output for a junction.

The entering of data for a large number of hydrologic elements can be tedious if single-element editors are used. The GUI contains global editors for entering or reviewing data of a given type (e.g., values for Green & Ampt parameters) for all applicable elements. If the same data values are being displayed in more than one GUI screen, a change in one screen will automatically be reflected in the other(s).

Because HEC-HMS contains a number of options for various types of computation, the specific option for a particular application must be chosen. In many cases, the user will choose to use the same option throughout a basin model (e.g., the Green & Ampt method for all subbasins). The user can set default method selections so that repetitive option designation is not required.

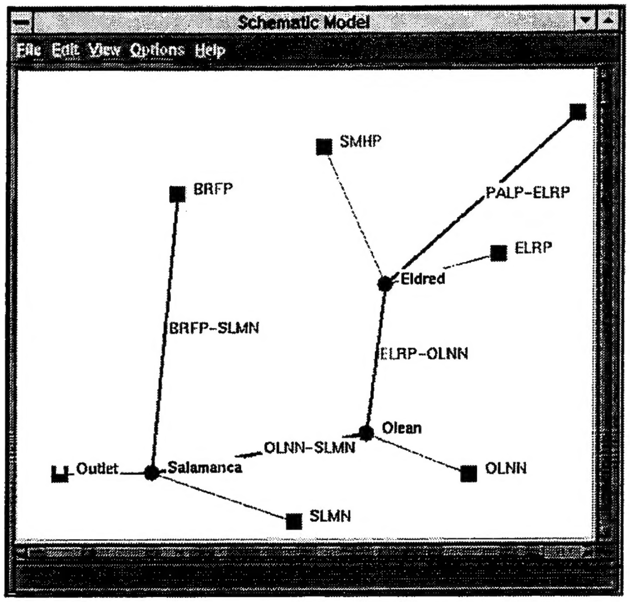

Figure 3. Schematic Representation of Network of Hydrologic Elements

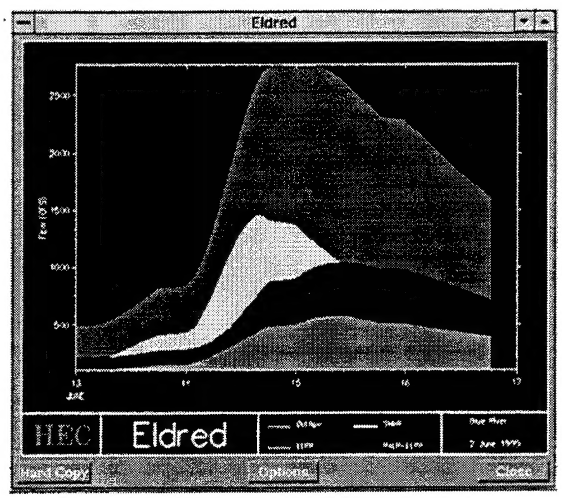

Figure 4. Junction Hydrographs

A GUI can provide a very useful means for user interaction with simulation software. However there are situations where it is desired to repeat a series of runs with minor variations in model parameter values, or to run the software under control of another modeling process. It is planned to develop a scripting capability such that HEC-HMS can be driven with macros that contain both control instructions and data values.

SOFTWARE ARCHITECTURE

HEC-HMS is designed to be operational in both native X-Window and Microsoft Windows environments. The HEC Data Storage System (HEC 1994a) is used for storage and retrieval of time series records in a manner largely transparent to the user. Existing computational algorithms from HEC-1 have been incorporated in a library for access by HEC-HMS (HEC 1994b). The computational "engine" is being developed with object-oriented programming with C^{++} (Charley et al., 1995). Integrated use of HEC-HMS with other HEC software such as the River Analysis System (HEC 1995c) and software for flood damage evaluation, reservoir system analysis, etc. is being accommodated.

FUTURE DEVELOPMENT

Capability for semi-automated estimation (optimization) of parameter values is being developed. The scheme for optimization will be flexible with regard to choice of parameters for optimization and basin location and type of objective function. Enhanced capabilities for distributed modeling will be developed. Provision will be made for automated adjustment of discharge-frequency curves for alternative watershed conditions (e.g., land use changes). These capabilities along with soil moisture accounting and simulation of snow accumulation/melt are the primary areas where future development will be focused.

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